Moving and Stationary Target Detection based on TI's IWR1843BOOST Platform

Shaoqiu Song, Yujun Deng, Xinran Duan, Rui Xie and Kai Luo

***Abstract*—In this paper, the moving and stationary target detection based on the IWR1843BOOST platform is considered where a target detection scheme is proposed. In the proposed scheme, the moving target signal is extracted from the received beat signal by using the differential coherent phase method. Then, the superresolution algorithm is used to obtain the measurements (i.e. range, velocity and angle) of the target. Moreover, the stationary target and the clutter are distinguished based the range and angle measurements. To delete ghost targets and compensate for missing targets, the target tracking strategy is considered for the moving target. Finally, the scene is reconstructed by combining the results of the moving and stationary target detection.**

***Index Terms*—Moving and stationary target detection, differential coherent phase, superresolution, moving target tracking.**

I. Introduction

The millimeter-wave radar attracts much attention recently due to an increasing demand of the localization accuracy in many applications[1]. The millimeter-wave spectrum offers a wide bandwidth to help radars achieve higher range accuracy with smaller antenna footprints. Moreover, the millimeter-wave radar has the ability to penetrate curtain and gather information on concealed objects. Therefore, it is widely used in many fields such as automotive electronics, unmanned aerial vehicle and intelligent transportation[2][3].

Generally, FMCW (Frequency Modulated Continuous Wave) is very popular in the millimeter-wave radar, mainly because is FMCW enables simpler hardware and architecture types[4]. Specifically, the FMCW radar does not instantaneously occupy a wide frequency bandwidth, hence the signal sweeps its frequency with time. Thus, the frequency of the target echo signal sweeps with time. In a certain period, as shown in Fig.1, there is a fixed frequency difference between the transmitting signal and the target echo signal, which is related to the distance of the target. Therefore, the signal characteristics not only simplify the hardware architecture of the FMCW radar, but also provide guidance for simple radar signal processing algorithms. In particular, the processing method known as fast-ramp based 2D Fast Fourier Transform (FFT), which directly processes the beat frequency measurement, is a very effective method[5]. The relatively lower beat frequency bandwidth significantly reduces the requirement for the high-speed data acquisition. Therefore, such an easily integrated detection system has been used in many researches, such as monitoring human movements[6], indoor presence detection[7], millimeter-wave imaging[8] and so on.

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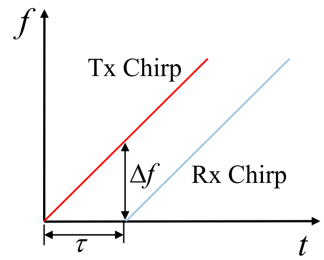

Fig. 1. The signal characteristic diagram of the FMCW radar.

In "Radar-A-Thon" radar challenge, a number of stationary and moving objects hidden behind a curtain are required to be sensed and detailed in the scene[9]. The scene is considered to be set up in a room with a maximum depth of 20m. The accuracy of measure parameters, such as location, velocity, angle, as well as the cost have to be concerned in the challenge. Therefore, the IWR1843BOOST, a FMCW millimeter-wave radar developed by Texas Instruments, is used to achieve these goals in our project. The IWR1843BOOST provides multiple antennas with low cost, which makes it possible to measure the range, velocity and angle of the target[10].

Generally, using a 2D FFT based detection algorithm, FMCW millimeter-wave radar is easy to distinguish between a moving target and clutter. Nevertheless, the stationary target or the slow Doppler target could be masked by the clutter or the side-lobe of the clutter. Thus, it is an urgent problem to obtain the information of a stationary target from the clutter. In [11], a differential coherent phase method is proposed to suppress stationary echoes. However, the stationary targets detection in the strongly clutter environments is not considered. Therefore, in this paper, a joint space and time differential coherent phase algorithm is used to distinguish the moving target, the stationary target and the clutter. Then, the velocity and angle measurements of the stationary and moving target are extracted using the superresolution method. Finally, the scene is reconstructed based the measurements of various targets.

Rest of the paper is organized as follows. Section II provides a description of the IWR1843BOOST platform. Moreover, the proposed scheme to distinguish the moving target, the stationary target and the clutter is given in Section III. Finally, the conclusion is drawn in Section IV.

II. IWR1843BOOST Based FMCW Radar Platform

The IWR1843BOOST is an integrated single-chip millimeter-wave radar system based on FMCW technology. The system includes an ARM R4F-based processor subsystem, which is responsible for front-end configuration, control, and calibration. An integrated DSP subsystem, which contains a TI high-performance C674x DSP for the radar signal processing, is also embedded in the IWR1843BOOST. The block diagram of IWR1843BOOST is shown in Fig. 2. Moreover, the IWR1843BOOST includes three transmitted antennas and four received antennas. Each receive channel consists of the low noise amplifier, the quadrature mixer, the IF filtering, the analog digital converter (ADC) and the decimation. Then, the I and Q outputs are transmitted to the computer through the UART. The front view of the IWR1843BOOST is shown in Fig. 3 and the relevant bill of materials are listed in Table 1.

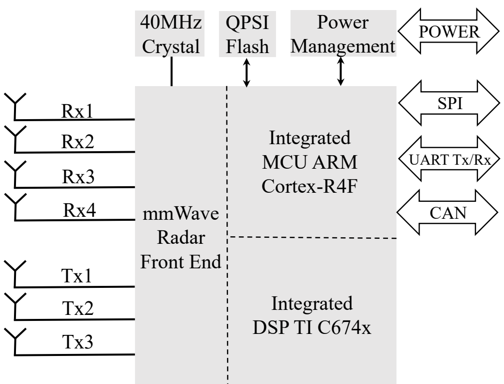

Fig. 2. The block diagram of the IWR1843BOOST.

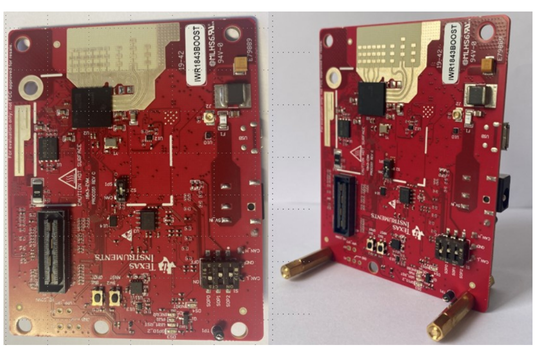

Fig. 3. The front view of the IWR1843BOOST.

TABLE I: The relevant bill of materials

Material	Source	Price
IWR1843 boost	TI	$ 299
Data cable & power adapter	others	< $ 20
Total		< $ 319

The detection range of the IWR1843BOOST is a primary concern of the millimeter-wave radar, which is related to the radar system parameters, the detection algorithm setting, and the physical characteristics of the environment and target. The official test results of the IWR1843BOOST are given in Table 2, which shows that the IWR1843BOOST has ability to detect small targets. The detection range could be further improved since the advanced signal processing algorithms can improve the accumulation gain.

TABLE II: The detection range of the IWR1843BOOST

Object	The detection Range
Motorbike	80 m
Human	40 m
Metal chair	30 m
Wooden chair	20 m
Plastic chair	10 m
Large dog	10 m
Small dog	5 m
Coins	1 m

III. Proposed Target Detection Scheme

In this section, the fundamental radar signal processing of FMCW radar is first introduced. Then, our proposed scheme, which mainly consists of the moving target signal extraction, the joint space and time superresolution estimation and the moving target tracking, is described.

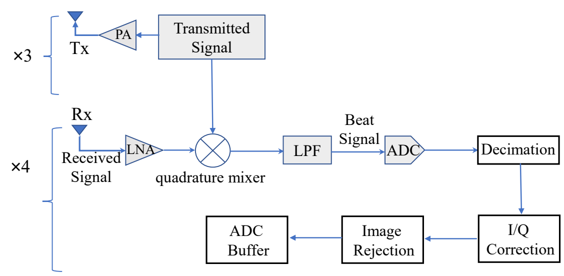

Fig. 4. The signal flow in the IWR1843BOOST.

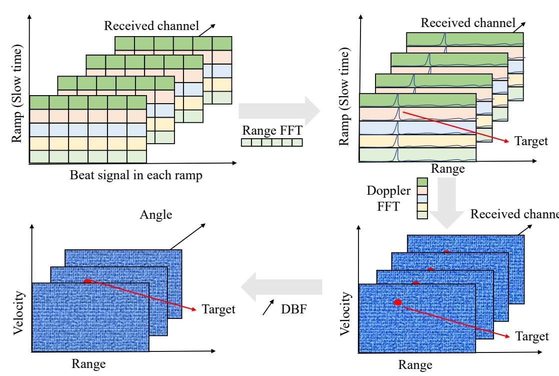

Fig. 5. The fundamental target detection algorithm for the IWR1843BOOST based FMCW radar.

A. *Fundamental Radar Signal Processing*

Based on the IWR1843BOOST platform, the traditional signal processing algorithm is introduced. As shown in Fig.

4, the IWR1843BOOST outputs the beat signal, which is the quadrature mixed signal of the received signal and the transmitted signal. If the target locates at the distance d, there is a delay τ between the received reflected signal and the transmitted signal. Then, the beat signal can be expressed as

$$x(t) = e^{j\pi u t^2} \cdot e^{-j\pi u (t-\tau)^2} = e^{j2\pi u\tau t - j\pi u\tau^2} \quad (1)$$

The frequencies of the received beat signals are related to the range of the targets. Thus, the FFT processing is used to obtain the range of the target. Since the transmission time is much shorter that the movement time of the target, the beat frequencies remain unchangeable in all ramps. Nevertheless, the phase of all beat signals are changed by the Doppler frequency of the target, which is corresponded to the velocity. Thus, the Doppler of every range-bin is estimated by FFT in the slow time. Moreover, the direction of arrival (DOA) of the target is estimated by using DBF (Digital Beam Forming). The fundamental target detection algorithm for the IWR1843 boost based FMCW radar is shown in Fig. 5.

B. Proposed Target Detection Scheme

In our FMCW radar, the received beat signal is digitalized into $r_{l,k,\theta}$ by the ADC, which is expressed as

$$\begin{aligned} r_{l,k,\theta} = w_{l,k,\theta} &+ \sum_{m=1}^{M} A_m e^{j2\pi(l-1)f_{rm}T_s} e^{j2\pi\phi_m} \\ &+ \sum_{n=1}^{N} A_n e^{j2\pi(l-1)f_{rn}T_s} e^{j2\pi(k-1)f_{Dn}T} e^{j2\pi\psi_{nk}} \quad (2) \\ &(1 \leq l \leq L, 1 \leq k \leq K) \end{aligned}$$

where L is the sampling number in one ramp, K is the number of the ramps, M is the number of the clutter (included the stationary target) and N is the number of the moving target. Moreover, A_m and A_n represent the corresponding amplitude, f_{rm} and f_{rn} are the corresponding beat frequencies, and f_{Dn} is the Doppler frequency of the moving target. ϕ_m and ψ_{nk} are the initial phase of the signal reflected from the corresponding scatterers, which are related to the DOA information. In addition, T_s is the sampling interval, T is the repeat interval of the ramp, and $w_{l,k,\theta}$ is the noise.

In the second term of (2), the initial phase ϕ_m remains nearly unchangeable over slow time since the Doppler frequency does not occur. In contrast, if the target is moving during the transmitting time, the phase of the beat signal changes, namely the differential coherent phase $f_{Dn}T$ and $\Delta\psi_{nk}$ occur between two successive ramps, as shown in the third term of (2). For a low maneuvering target, the differential coherent phase $\Delta\psi_{nk}$ can be regarded as a constant which is related to the radial velocity of the target, denoted by $f_{\psi n}T$. Then, the total differential coherent phase is $\Delta\psi_n = f_{Dn}T + f_{\psi n}T$.

Then, the first step of our proposed scheme is to separate the clutter and the stationary target signals from the received beat signal (2). Noted that the phases of the moving target changing over the ramps can be cancelled out if K is high enough, thus, using the coherent integration over all ramps, the clutter and the stationary target signals can be extracted. That is

$$\begin{aligned} C(r,\theta) &= \frac{1}{K}\sum_{k=1}^{K} \mathrm{FFT}(r_{l,k,\theta}) \\ &= w_{l,\theta}^{s} + \sum_{m=1}^{M_r} A_m e^{j2\pi\phi_m} \\ &+ \frac{1}{K}\sum_{k=1}^{K}\sum_{n=1}^{N_r} A_n e^{j2\pi(k-1)f_{Dn}T} e^{j2\pi\psi_{nk}} \quad (3) \\ &\simeq \sum_{m=1}^{M_r} A_m e^{j2\pi\phi_m} + w_{l,\theta}^{s} \end{aligned}$$

where $\mathrm{FFT}(\cdot)$ represents the range FFT of $r_{l,k,\theta}$, and r in the coherent integration $C(r,\theta)$ denotes the corresponding range bin. Moreover, M_r is the number of the clutter and the stationary targets in the corresponding rth range bin, and N_r is the number of the moving targets in the corresponding rth range bin.

Based on (2) and (3), the moving target signals in the rth range bin can be expressed as

$$\begin{aligned} D(r,\theta) &= \mathrm{FFT}(r_{l,k,\theta}) - C(r,\theta) \\ &= \sum_{n=1}^{N_r} A_n e^{j2\pi(k-1)f_{Dn}T} e^{j2\pi\psi_{nk}} + w_{l,\theta}^{m} \quad (4) \end{aligned}$$

Subsequently, the second step of the proposed scheme is to reconstruct the detection scene based on (3) and (4). In (3), the signals received from the clutter and the stationary targets is only related to the DOA information. Then, it is easy to obtain the DOA information by using the DBF. Nevertheless, the resolution of the target is poor since the number of the received antennas is small. Then, the superresolution algorithm is considered to be used to estimate the DOA of the targets. Generally, the DOA information can be obtained in one ramp. To improve the estimation accuracy, the data over several ramps, namely increasing the number of snapshots, can be used. Moreover, the stationary scene is updated over the transmitting time.

Furthermore, for the moving target, the Doppler frequency and the DOA are jointly estimated by using the data over several ramps and four received antennas. In our proposed scheme, the slow time is regarded as a "time" array. Then, the data over several ramps and four received antennas can be reconstructed as the data collected by a space and time 2D virtual array. Using the superresolution algorithm of 2D array, the Doppler and DOA information can be obtained.

Therefore, the scene, which contains the stationary scatterer distribution and the moving target tracking, is reconstructed with the above measurements. For the stationary scatterer, the range and the angle of the scatterer are used to determine its location. The 2D stationary scatterer distribution can be obtained by drawing such scatterers together. According to the 2D stationary scatterer distribution, the clutter and the stationary target can be distinguished by using some priori information.

Moreover, in terms of moving target detection, the ghost targets may exist and some targets may be missed. Thus,

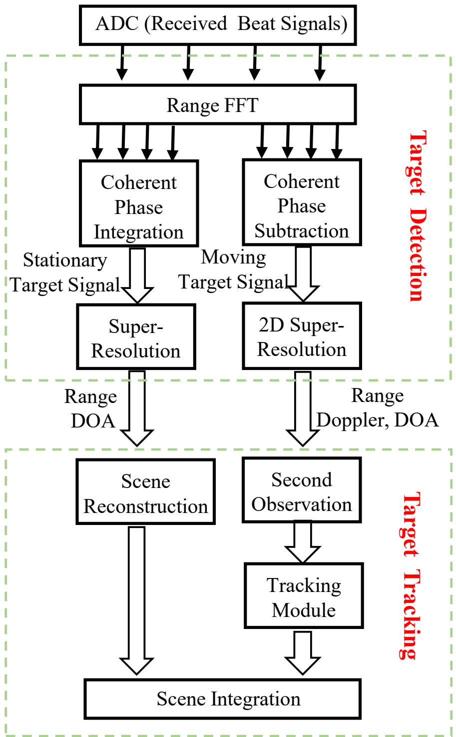

Fig. 6. The proposed signal processing scheme.

the moving target tracking is essential, which consists of the second measurement calculation, the data association, the track management and a track filter. In the stage of the second measurement calculation, the range, the Doppler and the angle of the moving target are used to calculation its location and velocity. Then, It is possible to judge whether the measurements at adjacent times are from the same target by using the location and velocity information, which is the key idea of the data association. The track filter is used to estimate the track state from the given measurements, with the predictions then calculated for the next state. The distance relationship between predicted state and the estimated state will be used as the judgment basis of data association. In the actual field, the track management is required since multi-targets track is common. The track management consists of starting track, maintaining track and terminating track.

Then, combining the results of the stationary scatterer distribution and the moving target tracking, the clutter, the stationary targets and the moving targets can be distinguished from the detection image. Based on the above description, our proposed signal processing scheme is summarized in Fig. 6.

IV. Conclusion

Based on the IWR1843BOOST platform, a joint time and space radar signal processing scheme is proposed for the moving and stationary target detection. First, the stationary target signal and the moving target signal are distinguished by using the differential coherent phase information. Then, different processing methods are adopted for these two type of signals. For the stationary targets and the clutter, the array information is used to classify them and reconstruct the stationary scene. For the moving targets, the moving target tracking is used to reduce the impact of ghost targets and produce some tracks. In the future work, the IWR1843BOOST radar system will be tested to demonstrate that its ability to detect moving targets and stationary targets.

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